Can We Distinguish Biological Motions of Virtual Humans? Biomechanical and Perceptual Studies With Captured Motions of Weight Lifting

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Can We Distinguish Biological Motions of Virtual Humans? Perceptual Study With Captured Motions of Weight Lifting.

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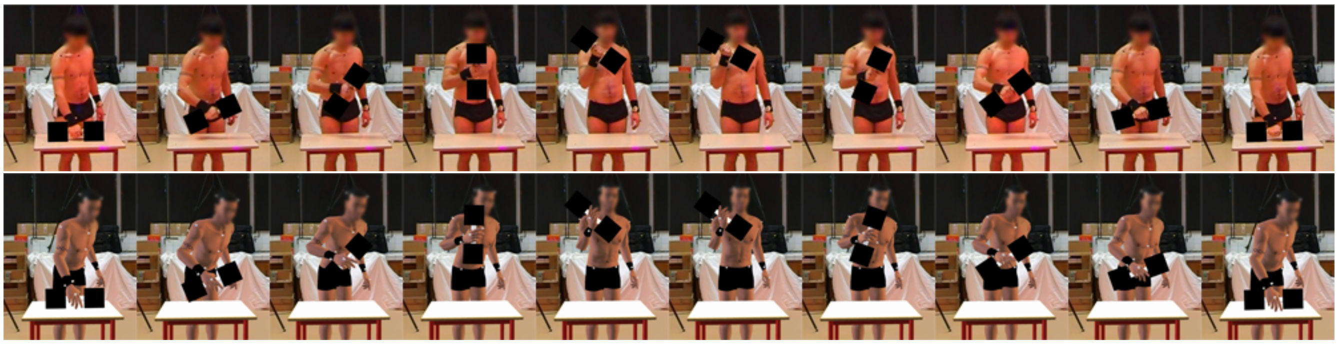

Figure 1: *Subject lifting a 6kg dumbbell: video of a real motion (up) and corresponding captured motion applied to a virtual human (down).*

Abstract

Perception of biological motions is a key issue in order to evaluate the quality and the credibility of motions of virtual humans. This paper presents a perceptual study to evaluate if human beings are able to accurately distinguish differences in natural lifting motions with various masses in virtual environments (VE), which is not the case. However, they reached very close levels of accuracy when watching to computer animations compared to videos. Still, quotes of participants suggest that the discrimination process is easier in videos of real motions which included muscles contractions, more degrees of freedom, etc. These results can be used to help animators to design efficient physically-based animations.

CR Categories: H.1.2 [Models and Principles]: User/Machine Systems—Human factors H.5.1 [Information Interfaces and Presentation, (e.g. HCI)]: Multimedia Information Systems—Animations – Artificial, augmented, and virtual realities

Keywords: Human Motions, Dynamics, Perception in VR

1 Introduction

Nowadays, more and more applications integrate virtual humans performing various interactions in VE. Animating virtual humans to perform these tasks involves taking many constraints into account, including dynamics properties of VE. It leads to using more or less accurate models which computation time is proportional to complexity. Hence, one main question arises: what is the minimal accuracy required for these models to create realistic animations and interactions with a user? Realism is difficult to understand but this idea is clearly linked to the perception of users. When it comes to motions where dynamic plays an important role, one may wonder how dynamic properties of motions are perceived by users both in real and virtual environments.

Previous studies showed that it is possible for human beings to perceive dynamic properties of such type of motions by looking at different performances [Runeson and Frykholm 1981]. However, to our knowledge, no work has ever been done to study if the perception of such dynamic properties is modified in VE.

In this paper, we present a perceptual study to evaluate if human beings are able to distinguish differences in biological captured motions, using weight lifting motions. We captured a set of motions lifting different weights, with a narrow mass scale from 2 to 10kg with a 1kg step. The study focuses on the level of accuracy reached by participants when comparing real (videos) or virtual motions. An overview of the method is presented in Figure 2. For the VR community, the idea that guides this paper is to determine if the process of transforming real motions into virtual ones preserves the capacity of the user to perceive the different dynamic properties. Section 2 presents works related with the animation of virtual humans and the perception of dynamic properties. Section 3 presents the perceptual study. Then, Section 4 discusses the results and Section 5 concludes and gives some perspectives to this work.

2 Background

One of the main challenge in computer animation is to generate highly realistic motions. Although [Johansson 1973] have shown that global human motion can be perceived from only a small set of representative points, the problem becomes more complex when the motion is applied to a realistic virtual human [Hodgins et al. 1998]. Hence simulating realistic motions generally relies on adapting motion capture data [Gleicher 1997; Witkin and Kass 1988; Kovar et al. 2002] to kinematic and dynamic constraints. Most of the approaches proposed in the computer animation literature can

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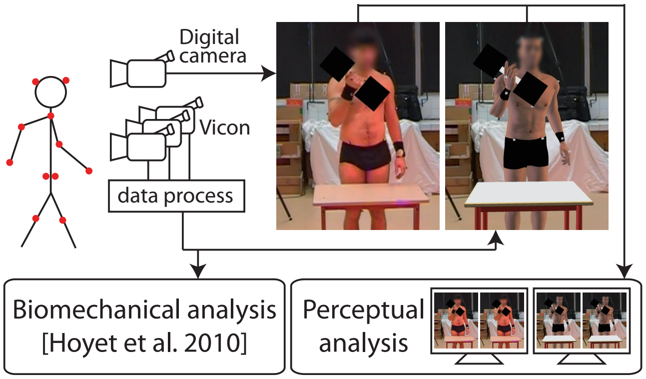

Figure 2: *A biomechanical analysis showed that statistical difference can be observed in joint kinematics of lifting motions associated with different masses [Hoyet et al. 2010]. Videos and captured motions applied to a virtual human are used in the perceptual study.*

deal with dynamic constraints with different levels of accuracy and computation time. A key question is to determine which level of accuracy is required to ensure realism. However, no generic means to evaluate the correctness or fidelity of virtual human animations exists. Different authors proposed metrics to evaluate the fidelity or closeness of animations, but they are still specific to a given problem [Arikan et al. 2005]. [Safonova and Hodgins 2005] evaluate the physical correctness of interpolated motions and make suggestions for the generation of natural looking motions. However, these metrics or predictors cannot quantify the actual sensitivity of the users to evaluate if the motion of a virtual human is appropriate to the current dynamic constraints.

[O'Sullivan et al. 2003] evaluated perceptual skills for the specific case of collisions between simple objects. They established non-symmetric thresholds for human sensitivity to dynamic anomalies through psychophysical experiments. They also showed that the tolerance for certain types of errors is significantly higher with the choice of realistic scenarios [Reitsma and O'Sullivan 2009]. [Reitsma and Pollard 2003] evaluated users' sensibility to errors in human motions, for the specific case of ballistic motions.

Most of these previous works focused on establishing if a simulated motion is perceived as realistic or not. A complementary problem consists in stating if correct simulated motions convey the appropriate dynamic properties associated with the action performed by the virtual human. For example, is the user able to recognize a 5kg-lifting motion compared to a 4kg one? [Runeson and Frykholm 1981] asked subjects to evaluate the mass of a box lifted and carried by an actor represented either with bright patches or normally. Results showed that the mass of the box was well specified in the pattern of the motion, participants managing to linearly estimate the mass of the lifted box, with an average slope of 0.87 and a deviation of 3.8kg. It is thus possible to estimate the mass of a box, but with a limited accuracy. For simple dynamics collisions between spheres, they showed that dynamics can be usually perceived through kinematic [Runeson et al. 2000]. When dealing with human motions, Bingham [Bingham 1987] showed that these dynamic properties are perceived through kinematic data of motions.

Complementary to the work presented in this paper, we have shown that statistical significant differences exist in joint kinematics of captured motions of weight lifting, even with only a 1kg difference of mass [Hoyet et al. 2010]. In the present paper, we focus on the perception of the minimal noticeable difference of lifted mass. Contrary to the work of Runeson and Frykholm, who used a wide mass scale of [4 10 16 22 28], we focus on small differences between masses within a scale ranging from 2kg to 10 kg with a 1kg step. Thus, we address the following question: "From the perceptual point of view, can humans perceive differences in biological captured motions of virtual humans lifting weights in VE?".

3 Perceptual study: can humans perceive differences in biological captured motions in virtual environments

This experiment focuses on the perception of weight lifting motions using videos and captured motions. Participants were exposed to pairs of lifting motions and had to estimate which motion corresponded to the heaviest mass. Each pair was composed of either videos of real motions (real condition) or captured motions applied to a virtual character (virtual condition). To study the perception of mass differences, each pair is composed of a 6kg lifting motion reference and a motion lifting a mass different from 6kg.

3.1 Method

Eighteen naive participants (15 males, 3 females) took part in this experiment (mean age: 26.83 years, SD: 5.77 years). All participants had normal or corrected-to-normal vision. Participants gave their informed consent prior to the experiment. As it included two different stimuli, participants were separated in two groups representing the two possible orders of the presentation of stimuli.

3.1.1 Stimuli and Apparatus

Setup Participants were comfortably seated at their preferred distance of a 20inches desktop screen with a resolution of 1,600×1,200 pixels, on which motions were displayed. The visual stimulus consisted of the display of lifting motions associated with different masses, either as videos or captured motions applied to a virtual human (Figure 1). The experiment runs on a standard computer (2.66GHz Dualcore processor, 2Go RAM, NVidia Quadro FX 3500). Videos of real motions were displayed at 25fps (capture frame rate of the camera) and virtual motions were displayed in real-time (120Hz). Each video corresponds to a unique captured motion. In order to eliminate the cues provided by the dumbbell and subject facial expressions, real and virtual motions were processed by masking the dumbbell and blurring the subject's head.

Displayed motions Motions were captured using a 12 camera VICON MX motion capture system synchronized with a video camera (25Hz capture rate, resolution of 720×576 pixel). The video camera was placed at eye's height, far enough from the scene to capture the subject from head to mid-calf.

3.1.2 Procedure and experimental design

Each participant performed 320 trials, consisting of a factorial combination of 2 conditions (real and virtual) × 8 pairs of motions × 20 repetitions of each condition (the reference motion was displayed first in half of the repetitions). The 8 pairs correspond to the 8 different couples of motions made of the 6kg reference motion compared with a motion lifting a mass of 2, 3, 4, 5, 7, 8, 9 or 10kg. After each trial, participants indicated the motion which seemed carrying the heaviest mass by clicking on the corresponding button (2-Alternated Forced Choice protocol). They also gave a confidence mark concerning their answer from 1 (not sure at all) to 7 (totally sure) on the Likert scale.

Participants were shown examples of the task before each session. Then, they started when ready. Both motions were successively displayed on the screen. Participants were allowed to give their answer after the end of the second motion. A break was set up every 15 minutes. Participants were given as much time of rest as needed. They were asked to fill-in a final questionnaire after the last session, and intermediate questionnaires after each session.

3.2 Results

Performance Participants were separated in two groups corresponding to the two possible presentation orders. No significant difference appear between groups using a Two Way RM ANOVA (Tukey's test with $p < 0.05$) on the effect of the group (F(1,2)=1.520, $p = 0.235$ for real condition results and F(1,2)=1.112, $p = 0.307$ for virtual condition results). Figure 3 presents the percentage of comparisons where each compared mass $m_j \in [2..10], j \neq 6kg$ is considered heavier than the reference mass of 6kg for real (blue bars) and virtual (green bars) conditions.

For the real condition, light masses (2kg and 3kg) present high discrimination performances when compared with the 6kg reference (considered lighter in 97.5% and 95.28% of the cases). The 10kg mass is estimated heavier than 6kg in 75% of the cases, while the 4kg mass, closer to the reference, is still correcly estimated in 71% of the cases. Results for other masses are more difficult to interpret. The 5kg mass is considered mainly heavier than the reference, while masses of 7kg and 8kg are considered heavier than the reference in less than 30% of the cases. The 9kg mass is considered slightly heavier than the 6kg reference (58%). Furthermore, standard deviations are globally high.

To study the effect of the condition (real versus virtual) on the mass perception, we ran a Two Way ANOVA with Repeated Measures using Tukey's test ($p < 0.05$) on the effect of the condition. No significant differences were found between the real and virtual conditions (F(1,2)=4.214, $p = 0.056$). This suggests that users tend to perceive differences between lifting motions in real and virtual environments with similar accuracy.

Regarding the results of the experiment, it seems that the perception of lifting motions is very close in real and virtual environments. However, human beings are globally not able to accurately perceive small differences on lifting motions for a mass scale from 2 to 10kg. Regarding results in Figure 3, it seems that a difference is perceived when comparing the 6kg reference with masses under 4kg and above 9kg. It corresponds to a difference of 50% of the reference mass for our special case, with a possible non symmetric difference between comparisons with lighter and heavier masses. Under this threshold (approximate JND), humans are not able to accurately estimate which motion is lifting the heaviest mass. However, if this mass perception step seems correct for light masses compared with 6kg, it might be underestimated for heavier masses.

Questionnaire Some questions included in the questionnaire were related to the cues used by subjects. Participants had to select criteria that they used for comparing motions (Table 1). Results show that participants mainly used velocity over position-based cues. Some subjects specifically reported to have especially used "velocity at the beginning of the lifting" and "velocity just before putting the dumbbell back on the table".

Many participants also reported to have used shoulder velocity to compare motions. However, this criterion failed to distinguish the joint kinematics of captured motions in [Hoyet et al. 2010]. Three participants did not answer these specific questions and were not able to tell which criterion they had used.

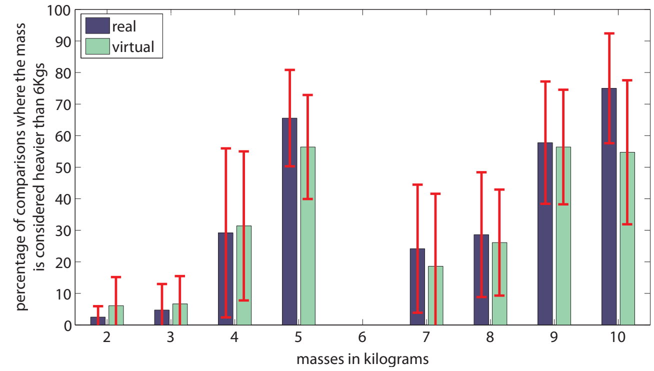

Figure 3: *Percentage of comparisons where compared mass $m_j \in [2..10], j \neq 6kg$ is considered heavier than the reference mass of 6kg for real (blue) and virtual (green) conditions*

	Position	Velocity
Hand	2	6
Elbow	3	7
Shoulder	4	9

Table 1: *Questionnaire results: cues used by participants to discriminate lifting motions (Multiple answers were possible).*

Participants also reported to have used other cues such as muscle contractions for discriminating real lifting motions. Some participants changed their strategy between real and virtual conditions "because for virtual humans you do not see muscles contractions" or "in videos of real motions you can observe muscle contractions". One participant "expected to see muscle contractions on the virtual human". Many participants also reported to have used a more global strategy for comparing virtual motions: "global posture of the virtual human", "motion of the shoulders", "balance of the virtual character" or "the motion of the lifting hand". The fingers of the avatar were not animated and two participants reported that "the hand was static" or "I was a little bit disturbed by the hand not completely grasping the dumbbell". One participant reported: "I noticed that the fingers were not completely around the dumbbell bar, but it did not matter".

Realness of the animations was also a key point of the comments. Participants felt that animations were similar to real motions: "the way of lifting the dumbbell was really similar" or "the virtual human modifies its balance when lifting a weight". However, many participants reported feelings that virtual motions seemed lifting lighter masses: "virtual motions seem to give a lighter feeling of the mass" or "the absence of muscle contractions makes the virtual character more rigid, hence a sensation of lightening of the virtual lifted mass".

The similarity of the avatar with the real subject was also addressed by the comments, such as "the avatar was really similar to the subject". Only one participant had the felling that "the morphology of the real and virtual humans were different and gave the impression that weights were heavier for real motions".

The overall perception was that "comparisons were more difficult between virtual motions than between videos". One quote reports the overall difficulty: "the comparison is really difficult in 60% of the cases and quite easy in 30%, but almost never in between". This comment represents well the obtained percentage of accurately perceived masses .

4 General discussion

This paper presents a perceptual study to evaluate if human beings are able to distinguish differences in natural lifting motions with various masses in VE, by comparing the perception of weight lifting in videos or captured motions applied to virtual humans. When comparing real or virtual motions, participants reached very close levels of accuracy for both conditions. These results seem to show that human beings are able to compare almost as accurately real and virtual motions. Compared with the statistical analysis carried-out in [Hoyet et al. 2010], subjects are however not able to perceive as accurately differences in joint kinematics as biomechanical criteria do. Indeed, it seems that subjects perceived only a difference of at least half the mass of our reference motion.

Hoyet et al. [Hoyet et al. 2010] showed that velocity-based criteria appear to be good candidates to distinguish lifting motions. However, one may wonder if these criteria are in agreement with the cues used by users to visually compare lifting motions. Questionnaires filled by participants (section 3.2, Table 1) show that participants mainly used velocity over position-based cues.

Furthermore, many participants reported to have used other cues, such as muscle contractions, for discriminating real lifting motions. This information is not delivered in VE. They also reported that many details were erased in VE, forcing them to focus on relevant dynamic cues. Thus, the process transforming capture data in virtual 3D motions could work as a low-pass filter keeping only the relevant kinematic information. Despite this filter, performance of participants in VE was rather close to the one obtained with video.

Discrimination of masses close to the reference of 6kg are difficult to analyze and present an overall high standard deviation. It is not possible to correctly fit a psychometric function on the data to evaluate the Just Noticeable Difference (JND). Different participants achieve different levels of accuracy, some being better in estimating differences with lighter or heavier weights. The difficulty may also come from the selected motions. However, the variability of the human motion makes it impossible to ensure successive identical lifting motions for the same mass, and even two identical lifting strategies when lifting different masses.

Taken together, our results showed that the process of applying motion capture data to virtual humans does not seem to impair users' perception. It suggests that captured motions still possess the important dynamic properties of the real actor. The method presented in this paper can also be used to study other types of motions and measure the accuracy of users to discriminate variations of a given task in VE. The obtained knowledge could then be used to design only perceptually different motions for variations of the same task.

5 Conclusion

In this paper, we showed that human perception seems very similar in real and virtual environments. Participants were able to compare almost as accurately videos of real lifting motions and corresponding captured motions applied to a virtual human. Somehow, it shows that dynamic properties of natural motions are preserved during the animation process.

One of the main goals of this study is to provide animators with a better knowledge on the sensitivity of human beings to perceive motions of a virtual human. Results of this paper tend to suggest that there is no need to design motions with a 1kg resolution as it is not perceived by an external user. VE designers could thus design only limited sets of motions without decreasing the realism of scenarios. In the same way, it would be possible to run dynamic solvers only when the difference of mass is distinguishable. However, this work is a first step in the acquisition of knowledge about the perception of dynamic properties. It would be interesting to further extend the lifted mass scale to obtain better knowledge about the minimum perceived mass in VE. Different questions also arise about the scalability of mass perception. Should the minimum perception mass be expressed as a relative or an absolute value of the reference mass? Is this minimum perception mass linear when increasing the presented weights, as the estimation of the mass of the box was in [Runeson and Frykholm 1981]? Another lead concerns future studies of other highly dynamic motions.

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